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ELECTRONIC EQUIPMENT HANDBOOK ON METHODS FOR MEETING U.S. NAVY SHIPBOARD ELECTRICAL POWER INTERFACE REQUIREMENTS

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This handbook provides guidance for the implementation of electronic equipment suitable for U.S. Navy shipboard applications. The primary focus of this handbook is on the electrical power interface between combat systems equipment and U.S. Navy shipboard electrical power generation and distribution systems. A number of problems currently exist with this interface and electronic equipment. These problems have often resulted in decreased equipment availability and damage. In addition, there is a potential for similar design and operational problems when fielding commercial-off-the-shelf (COTS) equipment. This handbook describes these problems, as well as approaches that may be employed to resolve these problems.

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FOREWORD

This work was sponsored by the Naval Sea Systems Command (SEA 03R1) as part of the Combat Systems Power Improvement Program (CSPIP) at the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), Code N95. The CSPIP is an effort to develop and test new technologies for improving the survivability of combat systems equipment.

This handbook provides guidance for the implementation of electronic equipment suitable for U.S. Navy shipboard applications. Specifically, this handbook discusses methods for meeting the requirements specified in MIL-STD-1399, Section 300 (Interface Standard for Shipboard Systems, Electric Power, Alternating Current) and MIL-STD-2036 (General Requirements for Electronic Equipment Specifications). The purpose of this handbook is to provide approaches for resolving the electrical power interface problems currently encountered with some military equipment, and to prevent the potential design and operational problems when fielding commercial-off-the-shelf (COTS) equipment.

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PURPOSE

The primary goal of this handbook is to provide acquisition managers, engineers, and program managers with the information they need to properly select and implement electronic equipment, so that it will be suitable for U.S. Navy shipboard applications. Some of the information that will be provided includes a description of the electrical power interface problems, and some approaches that may be employed to help resolve these problems. The description of the problems will include discussions on what causes the problems and on what some of the impacts are resulting from the problems. The description of the approaches will include discussions about what the approaches are, why we need them, and how they should be implemented.

BACKGROUND

In 1981, the Naval Material Command (NAVMAT) initiated the Electric Power Interface Compatibility (EPIC) program. This program was in response to numerous complaints from the fleet concerning decreased equipment availability and damage due to electrical power interface problems with U.S. Navy shipboard electrical power generation and distribution systems. The majority of the reported problems fell into the following categories:

- conducted interference
- frequency and voltage variations
- power interruptions
- voltage spikes

An investigation revealed that many of these problems were related to a failure of the electronic equipment to meet the electrical interface requirements specified in MIL-STD-1399, Section 300 (Interface Standard for Shipboard Systems, Electric Power, Alternating Current) and MIL-STD-2036 (General Requirements for Electronic Equipment Specifications). In most cases, waivers were granted because it was believed that it would be too difficult or too expensive to modify the electronic equipment so that it conformed with the electrical interface requirements. As a result, a variety of solutions were examined and submitted in a proposal by prominent members of the EPIC committee. This proposal provided the basis for and eventual development of a new power supply approach called the Navy Standard Electronic Power System (NSEPS).

More recently, the Navy has been undergoing drastic changes in the way it does business. Part of these changes include a move to replace military specifications with commercial specifications and to procure commercial-off-the-shelf (COTS) equipment. The recent passage of the Federal Acquisition Streamlining Act, which modifies or repeals over 225 statutes, makes this procurement much easier. As a result, the potential design and operational challenges of using COTS equipment onboard U.S. Navy ships also needed to be addressed. An investigation into some of these challenges revealed a number of candidate commercial approaches that may be suitable for resolving some of the electrical power interface problems noted earlier. The candidate approaches that were identified included the following commercial equipment:

- uninterruptible power supplies (UPSs)
- power conditioners
- transient voltage surge suppressors (TVSSs)

The Naval Sea Systems Command (SEA 03R1) directed the Naval Surface Warfare Center, Dahlgren Division (NSWCDD), Code N95 to evaluate the commercial approaches and the NSEPS for compatibility against the electrical interface requirements specified in MIL-STD-1399, Section 300 and MIL-STD-2036. Descriptions of the electrical power interface problems, electrical interface requirements, and approaches that may be employed to help resolve these problems are listed in the paragraphs below.

ELECTRICAL POWER INTERFACE PROBLEMS

CONDUCTED INTERFERENCE

When several pieces of electronic equipment are connected to the same power source, the operational performance of some of the equipment may be adversely affected by a phenomenon known as conducted interference. A common example of this phenomenon occurs when we are at home trying to watch television and someone suddenly turns on a hair dryer or a vacuum cleaner. The distortion we see in the picture of the television is a result of conducted interference. Conducted interference is caused by harmonic currents. Whenever a piece of electronic equipment converts alternating current (AC) voltage to direct current (DC) voltage, the line current becomes distorted (current harmonics are generated). Equipment current harmonics can distort the voltage waveform and cause premature failure or erratic operation of other equipment connected to the same power source. As a result, equipment current harmonics should be kept as low as possible. MIL-STD-1399, Section 300 requires current harmonics to be limited to a maximum of 3 percent for any single harmonic and 5 percent for the total harmonic distortion.

FREQUENCY AND VOLTAGE VARIATIONS

Frequency and voltage variations are caused by sudden increases or decreases in the ship's electrical load. Whenever an air conditioning (A/C) plant, fire pump, or large motor is started, this sudden step-load increase causes the generator to slow down, resulting in a sag in the frequency and a corresponding dip in the voltage. Frequency sags and voltage dips can also occur when combat systems equipment shifts from stand-by to air-ready or from a passive mode to an active mode. Similarly, whenever an A/C plant, fire pump, or large motor is shut down, this sudden step-load decrease causes the generator to speed up, resulting in a rise in the frequency and a corresponding surge in the voltage. Frequency and voltage variations are a common occurrence on U.S. Navy ships because of the broad array of equipment that is constantly being turned on and off or being cycled through various modes of operation. Unfortunately, some combat systems equipment is adversely affected by the frequency and voltage variations. Relatively moderate variations in frequency and voltage may cause equipment to go into a self-protect mode and then shut down. As a result, some form of power conditioning may be needed to tighten up the frequency and voltage regulation on the input to the electronic equipment.

POWER INTERRUPTIONS

Momentary power interruptions (less than 150-msec) occur when automatic bus transfer (ABT) switches transfer to an alternate source, when fault conditions are cleared by circuit breakers, and when shock conditions cause the contacts of circuit breakers and relays to chatter. Short duration power interruptions (less than 5-min) occur when casualties to the ship's service generators and electric plant occur, requiring the start-up of emergency generators, restart of generators that have shut down, and the reconfiguration of the electrical distribution system through the use of manual bus transfer (MBT) switches by the ship's crew. Presently, very little is done to provide momentary or short duration energy storage for power interruptions. This problem has been exacerbated by the proliferation of high power density, switching mode power supplies, which typically have less than 50-μsec of hold-up. As a result, some combat systems equipment may be unavailable following momentary power interruptions. For example, extended restart times may be required for computers to reboot, and for radars and other systems using waveguides to warm-up following momentary power interruptions of only 20-msec in duration. In addition, some combat systems equipment can actually be damaged by a momentary power interruption. For example, internal damage to the AN/SQS-53B Sonar can occur if input power is interrupted during an active pulse mode. Added energy storage may be needed in some cases to allow vital combat systems equipment to operate through momentary power interruptions and to keep critical circuits energized during short duration power interruptions.

VOLTAGE SPIKES

Voltage spikes are usually caused by arcing ground faults. Line-to-ground voltages in excess of 2500 VDC can occur on ungrounded U.S. Navy shipboard electrical power distribution systems. Voltage spikes have been found to be a major cause of electronic equipment damage. The energy associated with these transients can be determined by using the equation $E = \frac{1}{2}CV^2$, where E represents the energy, C represents the capacitance between the electrical power distribution cables and the ship's hull, and V represents the peak amplitude of the voltage spike. This hull capacitance is largely a result of line-to-ground electromagnetic interference (EMI) filters on electronic equipment. As an example, the hull capacitance measured during ground fault testing on the *USS Vella Gulf* (CG-72) was approximately 74 μF. For the spike voltage tests required in MIL-STD-1399, Section 300, however, the capacitance used is 120 μF. The peak voltage amplitude used for 115-VAC systems is 1000 VDC, and for 440 VAC systems it is 2500 VDC. This gives an energy of 60 joules for 115-VAC systems and 375 joules for 440-VAC systems. Protective devices are needed that will dissipate this energy, thus preventing any subsequent damage to the electronic equipment.

ELECTRICAL INTERFACE REQUIREMENTS

MIL-STD-1399, Section 300 and MIL-STD-2036 establish the electrical interface requirements for U.S. Navy shipboard electrical and electronic equipment. When equipment does not meet these requirements, two situations may occur: (1) the electrical power generation and distribution system characteristics and tolerances are adversely affected or (2) the equipment does not function properly, often resulting in decreased equipment availability and damage. The purpose of these requirements is to ensure compatibility between electronic equipment and the electrical power generation and distribution system. MIL-STD-1399, Section 300 defines the electrical interface requirements for the design of shipboard equipment. MIL-STD-2036 provides guidance for specifying the electrical interface requirements for electronic equipment, and for the use of COTS, ruggedized, and militarized equipment.

The electrical interface requirements can be divided into two areas: equipment requirements and system requirements. The system requirements are basically a characterization of the maximum tolerances/conditions that may be found on the U.S. Navy shipboard electrical power generation and distribution systems. Electronic equipment is not only required to meet the equipment requirements, but also to operate/withstand the maximum tolerances/conditions of the system requirements. As mentioned earlier, an investigation revealed that many of the electrical power interface problems were related to a failure of the electronic equipment to meet the electrical interface requirements. As a result, each of the candidate approaches was evaluated by subjecting them to the maximum tolerances/conditions and by testing them for compliance with the equipment requirements. A summary of the electrical interface requirements can be found in Table 1.

TABLE 1. ELECTRICAL INTERFACE REQUIREMENTS

EQUIPMENT REQUIREMENTS	
Leakage Current	< 5 mA
Surge Current	< 10 Times Rated Input Current
Input Current Harmonics	3% Maximum for Any Single Harmonic 5% Maximum for the Total Harmonic Distortion
SYSTEM REQUIREMENTS	
Long Duration Excursions	+3% Frequency, +5% Voltage Indefinitely -3% Frequency, -5% Voltage Indefinitely
Short Duration Excursions	+5.5% Frequency, +20% Voltage for 2-sec -5.5% Frequency, -20% Voltage for 2-sec
Power Interruptions	150-msec Momentary Power Interruptions 5-min Short Duration Power Interruptions
Emergency Conditions	+12% Frequency, +35% Voltage for 2-min -100% Frequency, -100% Voltage for 2-min
Voltage Spikes	±1000 VDC Line-to-Ground, 2-/50-μsec Waveform for 115 VAC Equipment ±1000 VDC Line-to-Line, 2-/50-μsec Waveform for 115 VAC Equipment ±2500 VDC Line-to-Ground, 2-/50-μsec Waveform for 440 VAC Equipment ±2500 VDC Line-to-Line, 2-/50-μsec Waveform for 440 VAC Equipment

To evaluate the candidate approaches, a special test facility was needed. Fortunately, this test facility already exists and is located at Dahlgren, Virginia. The test facility is called the Combat Systems Electrical Power Mobile Test Facility (MTF). The MTF was designed by NSWCDD-N95 and represents a significant, capability for ensuring compatibility between combat systems equipment and shipboard electrical power systems.

The MTF consists of computer-controlled electric power generation and measurement equipment, housed in a 48-ft mobile trailer. The MTF can simulate electric power characteristics and analyze the effects on equipment performance. The MTF provides the capability to test equipment compliance with the electrical interface requirements prior to shipboard installation. The MTF is capable of varying its output parameters over the full range of MIL-STD-1399, Section 300 specifications. A letter of endorsement for the MTF from the Naval Sea Systems Command (SEA 03E and SEA 03K) can be found in Appendix B.

CANDIDATE APPROACHES

When fielding COTS equipment or when trying to properly select and implement electronic equipment, acquisition managers, engineers, and program managers are going to be faced with the electrical power interface problems noted earlier. The paragraphs below describe a number of candidate approaches that were evaluated for helping both commercial and military electronic equipment meet the electrical interface requirements of MIL-STD-1399, Section 300 and MIL-STD-2036. These approaches include the use of the NSEPS, UPSs, a power conditioner, and TVSSs. The description of the approaches will include discussions about what the approaches are, why we need them, and how they should be implemented. This information should be used as a guide when fielding COTS equipment or when selecting and implementing electronic equipment.

NSEPS

One approach that acquisition managers, engineers, and program managers concerned with decreased equipment availability and damage due to electrical power interface problems should consider is the NSEPS. The NSEPS acts as a buffer between the electronic equipment and the U.S. Navy shipboard electrical power generation and distribution systems. The NSEPS basically eliminates the electrical power interface problems by converting the shipboard AC voltage to a clean and stable DC voltage that is suitable for powering electronic equipment. The NSEPS has a number of unique features that allow it to do all this. A 21-phase transformer provides equipment isolation and reduces the harmonics. An electrostatic shield and a choke keep the voltage spikes suppressed. Frequency and voltage variations are not a problem, because the NSEPS regulates the DC output voltage. Finally, a bank of capacitors provides hold-up for momentary power interruptions of up to 150-msec and a bank of batteries provides hold-up for short term power interruptions of up to 5-min.

The NSEPS converts shipboard 440-VAC, 60-Hz, 3-phase power to 155 VDC to power Navy Standard Power Supplies, as specified in the general specification for power supplies.[1] This DC voltage was selected because it is the voltage resulting from rectifying 115 VAC, the Navy Standard Power Supplies operate from this voltage, and many existing equipment will operate from either 115 VAC or 155 VDC. Navy Standard Power Supplies are often used by the combat systems equipment to obtain the DC voltage levels needed for the individual equipment elements (e.g., ±5 VDC). It should be noted that the 155 VDC output is not a fixed requirement. The NSEPS design can be tailored to meet specific needs. As an example, one manufacturer acquired a version of the NSEPS that converts shipboard power to 270 VDC (vice 155 VDC). In addition to the 155 VDC output, the NSEPS also has a single-phase, 115-VAC output available for powering muffin fans and the like.

[1]Naval Weapons Support Center, Standard Power Supply Program, General Specification for Power Supplies, NAVSEA SE 010-AA-SPN-010.

An evaluation of the NSEPS revealed that it could actually be classified as a fully militarized unit. The NSEPS met or exceeded all the electrical requirements specified in MIL-STD-1399, Section 300 and MIL-STD-2036. Although some of the frequency and voltage excursions specified in MIL-STD-1399, Section 300 only required a 2-sec or 2-min duration test, the NSEPS was operated for several hours during these conditions. In addition to the electrical tests, the NSEPS also withstood several harsh environmental tests, which included humidity (according to MIL-STD-810, Method 507.3, Section II, Procedure I), shock (according to the Type A, Grade A, medium-weight shock requirements for Class II equipment as specified in MIL-S-901D), temperature (according to MIL-STD-810, Methods 501.3 and 502.3, Procedure II), and vibration (according to the Type I vibration requirements specified in MIL-STD-167-1). It should be noted that the NSEPS was operating at full load and with the input voltage and frequency at nominal levels, during all of the environmental tests. Test data for the NSEPS can be found in the NSEPS technical report.[2]

There are several ways that the NSEPS may be implemented. One way is to incorporate the NSEPS into the design of a system or a large piece of equipment. The NSEPS could then be used to provide DC power for all the electronics. Another way is to supply the NSEPS as a stand-alone unit to provide DC power for smaller electronic equipment located within close proximity. It should be noted that the NSEPS is available in a number of different configurations, with ratings ranging from 10 kW to 40 kW in increments of 10 kW. The bank of capacitors is included and has the same ratings. The bank of batteries, however, is optional with ratings ranging from 2.5 kW to 10 kW in increments of 2.5 kW. The standard configuration for the NSEPS has a rating of 10 kW and a bank of batteries rated at 2.5 kW. The standard configuration measures 22-in wide by 22-in long by 53-in high, and weighs approximately 800 lb. Due to the size and weight of the NSEPS, its application may be limited to mission critical equipment.

UPS

UPSs have been in our homes and offices for a number of years. Equipment such as computers, displays, and printers are usually connected to a UPS to prevent shut downs during black-outs or brown-outs, and to provide protection in case of a lightning strike. Acquisition managers, engineers, and program managers have taken a similar approach with the COTS equipment now going onboard U.S. Navy ships. UPSs are often being used as a buffer between the shipboard 115-VAC, 60-Hz power and the COTS equipment. UPSs provide back-up power during short-term power interruptions and in some cases reduce harmonics, regulate the voltage and frequency, and provide voltage transient protection.

[2]Naval Surface Warfare Center, Combat Systems Power Improvement Program, Navy Standard Electronic Power System Electrical and Environmental Testing, NSWCDD/TN-98/40, 1998.

UPSs from a number of manufacturers were evaluated for conformance with the electrical interface requirements specified in MIL-STD-1399, Section 300 and MIL-STD-2036. Prior to the testing, compatibility and safety concerns were raised about the input power interface of the COTS equipment. Typically, COTS equipment operates with one AC input power line *hot* and the other line (return) grounded. Voltage to the COTS equipment is removed by simply interrupting the *hot* line. In a shipboard environment, the input power lines are floating (i.e., all the lines are *hot*). As a result, all the input power lines must be interrupted to remove voltage from the shipboard equipment. The compatibility concern was that the COTS equipment normally operating from a grounded power system may not be suitable for operation from a floating power system. The safety concern was that hazardous voltages may still be present inside the COTS equipment even though the input power switch has been secured.

Each of the UPSs was examined to determine if the compatibility and safety concerns were warranted. The examination revealed that most of the UPSs used either a two-pole circuit breaker or a relay powered contactor to remove power to both input power lines. In addition, all of the UPSs had an isolation transformer on the input to allow the UPS to operate with both input lines floating. This effectively eliminated the compatibility and safety concerns. It should be noted that the isolation transformers should also help reduce voltage spikes.

Testing revealed that most of the UPSs meet the frequency and voltage variation requirements, leakage and surge current requirements, and are able to withstand the emergency conditions and voltage spikes (each UPS was subjected to 10 line-to-ground and 10 line-to-line voltage spikes of amplitude 1000 VDC) specified in MIL-STD-1399, Section 300 and MIL-STD-2036. Some of the UPSs had peculiar operating characteristics (e.g., a half-cycle loss of output voltage). Only a few of the UPSs tested were able to meet the harmonic requirements for equipment loads in excess of 1-kVA. The UPSs that were able to meet the harmonic requirements used some form of power factor correction (PFC). Test data for the UPSs can be found in Appendices A and B of the UPS technical report.[3] A draft commercial item description (CID) for UPSs can be found in Appendix A of this handbook.

There are several ways that the UPSs may be implemented. One way is to power several pieces of COTS equipment or even an entire space from a single a UPS. Another way is to power each piece of COTS equipment with its own UPS. This will have to be decided by the acquisition managers, engineers, and program managers. It should be noted that the UPSs come in a number of different sizes, configurations, and ratings. As a result, an acquisition plan should be developed so that there is some standardization when the UPSs are being purchased. Otherwise, a ship might wind up with hundreds of different UPSs, resulting in both logistics and maintenance nightmares. It is also important that any candidate UPSs be tested to verify conformance with the electrical interface requirements noted above.

[3]Naval Surface Warfare Center, Combat Systems Power Improvement Program, Evaluation of Commercial-Off-The-Shelf Uninterruptible Power Supplies (UPS), NSWCDD/TR-96/45, 1996.

POWER CONDITIONER

Power conditioners are normally used in industrial applications. These devices usually provide frequency and voltage regulation, and protect against power surges and lightning strikes. Acquisition managers, engineers, and program managers have been using power conditioners as a buffer between the shipboard 115-VAC, 60-Hz power and electronic equipment when only limited protection was required. Power conditioners have several attributes that make them desirable for use in a shipboard environment. One is their small size, and the other is the ease of tailoring these devices for specific applications. For example, the power conditioner that was evaluated came with 90-msec of hold-up and had several plug-in capacitor bank modules that could substantially boost the hold-up time.

As mentioned earlier, only one power conditioner was evaluated. The power conditioner was actually included in the evaluation of the UPSs. The performance of the power conditioner was comparable to that of the UPSs. It met the frequency and voltage variation requirements, leakage and surge current requirements, and was able to withstand the emergency conditions and voltage spikes. Although the power conditioner did not meet the harmonic current requirements, the manufacturer indicated that PFC circuitry could be added with relative ease.

Power conditioners may be implemented in the same manner as UPSs, however, individual pieces of COTS equipment will likely get their own specially tailored power conditioner. As with the UPSs, it is important that any candidate power conditioners be tested to verify conformance with the electrical interface requirements noted above.

TVSS

TVSSs are probably the most frequently used protective devices found in our homes and offices. These devices usually take the form of a power strip and provide protection against lightning strikes and power surges. Some of these devices even come with built-in circuit breakers or fuses. Not only do we protect office equipment like computers, displays, and printers, but we also protect our stereos, televisions, and even our telephones with these devices. Acquisition managers, engineers, and program managers have also been using TVSSs for a number of years to provide sensitive equipment with voltage spike protection. Although the application of TVSSs might appear to be an easy fix, in many cases the devices selected are too small and consideration is not given to the gradual degradation of these devices caused by a repetitive exposure to the voltage spikes. After only a short time of use, the TVSS may fail catastrophically, resulting in a loss of protection.

The most common TVSS device is the metal-oxide varistor (MOV). MOVs are typically composed of granules of zinc-oxide placed in a matrix of metal oxides. This material is then pressed and heated to form the MOV's ceramic body. The body usually takes the form of a circular disk (e.g., hockey puck). The electrical characteristics of the disk are determined by the diameter and thickness of the disk. The diameter is increased to raise the current capability and the thickness is increased to raise the breakdown voltage. MOVs are used as clamping devices and are connected in parallel with the electronic equipment that they are protecting. MOVs act like high-impedance devices until their normal operating voltage is exceeded (i.e., the breakdown voltage is reached). When this happens, the resistance of the MOV drops until it begins to conduct. The MOV then clamps the voltage until the spike is removed. Care should be taken to select a low enough clamping voltage so that it will not damage the electronic equipment.

Transient events often cause the granular interfaces of MOVs to overheat and short. As more and more interfaces are shorted, the MOVs are gradually degraded until a loss of protection occurs. For this reason, it is recommended that MOVs be rated an order of magnitude higher than the expected transient energy levels. Although a considerably higher energy rating will not prevent these devices from failing, it will increase their life expectancy. More frequent and longer-duration transients require the energy ratings of these devices to be derated even further.

Hybrid networks are combinations of several protective devices (e.g., carbon block, gas tube, MOV, transorb, etc.) arranged in series or parallel stages. This combination of protective devices is usually more effective than any single device because any deficiencies in a particular device (e.g., low energy dissipation, slow response time, etc.) can be eliminated by using some of the better qualities of the other devices. As with MOVs, conventional hybrid networks also degrade due to overheating of the protective devices.

TVSSs from several different manufacturers were evaluated for their durability and their effectiveness at clamping voltage spikes. The TVSSs included several different MOV and hybrid network models. The TVSSs were subjected to the same number of voltage spikes that they might expect to see during a 30-yr life in a shipboard environment. The number of voltage spikes selected was based on the 7-day histogram of voltage spikes in 440-VAC systems found in MIL-STD-1399, Section 300. During the 7-day period, there were 7 voltage spikes with an amplitude greater than 1000 VDC. This is equivalent to just 1 spike per day or approximately 10000 spikes over a 30-yr life. As a result, each TVSS was subjected to 5000 line-to-ground and 5000 line-to-line voltage spikes to simulate the 30-yr life. A Solar Voltage Spike Generator was used to place the voltage spikes on the input AC voltage waveform, as specified in MIL-STD-1399, Section 300. The 30-yr life used for the evaluation was condensed to approximately two weeks by subjecting the TVSSs to 1 spike approximately every 30-sec. Since the TVSSs were not given time to cool between successive voltage spikes, the simulated test conditions were perhaps harsher than the shipboard environment. A typical TVSS connection is shown in Figure 1. The results of the testing are discussed in the paragraphs to follow.

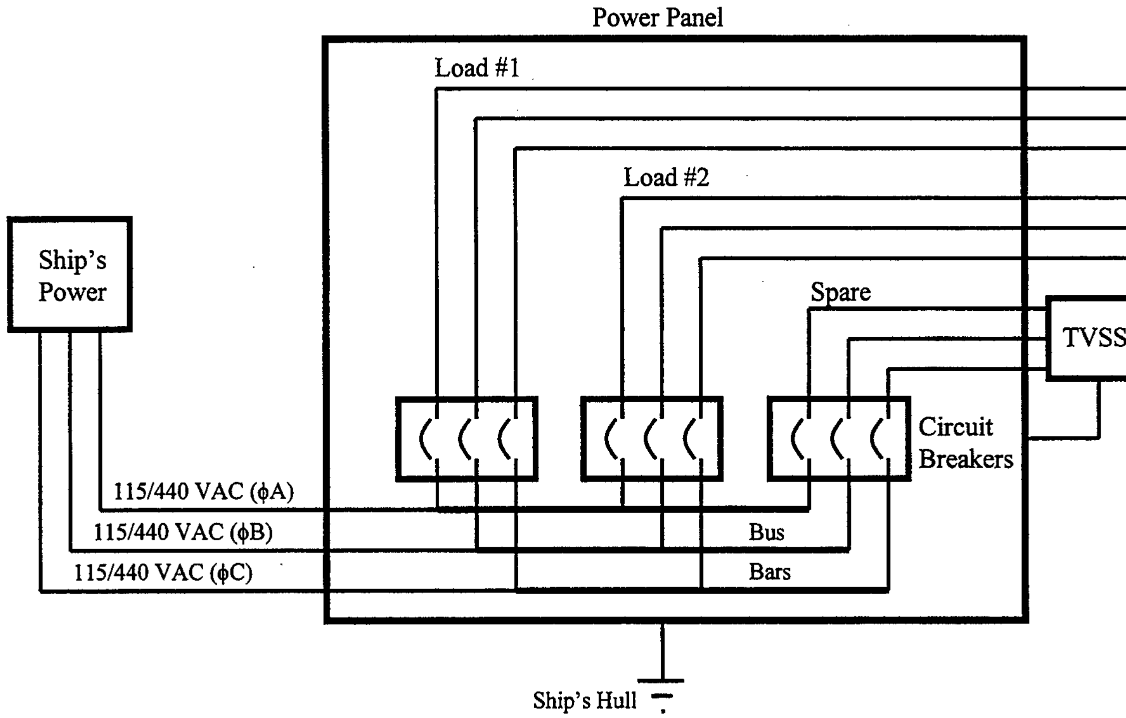

FIGURE 1. TYPICAL TVSS CONNECTION

On 17 June 1994, spike testing of several different MOV models was completed. 208-VAC and 240-VAC models were tested for the 115-VAC configuration, and several 480-VAC models were tested for the 440-VAC configuration. Energy ratings for the 208-VAC and 240-VAC models ranged from 280 joules to 360 joules, which is considerably higher than the expected transient level of 60 joules. The energy rating for the 480-VAC models was 390 joules, which is only slightly higher than the expected transient level of 375 joules. As expected, the 208-VAC and 240-VAC models operated successfully during the spike testing. The 208-VAC and 240-VAC models were able to withstand literally thousands of spikes without a failure. The 480-VAC models did not appear to be very durable. Each of the 480-VAC models failed catastrophically during the testing, even when two of the models were placed in parallel. A summary of the MOV test results can be found in Table 2.

TABLE 2. MOV SPIKE VOLTAGE TEST RESULTS

Model	Spike Voltage	Energy Rating (per phase)	Number of Line-to-Ground Spikes Applied	Number of Line-to-Line Spikes Applied	Result
208-VAC, 3-Phase	1000 VDC	280 joules	* 1700	1050	Passed
240-VAC, 1-Phase	1000 VDC	360 joules	7700	6000	Passed
240-VAC, 3-Phase	1000 VDC	360 joules	4300	6700	Passed
480-VAC, 3-Phase	2500 VDC	390 joules	50	0	Failed
480-VAC, 3-Phase	2500 VDC	390 joules	2	220	Failed
480-VAC, 3-Phase 2 Units in Parallel	2500 VDC	390 joules	190	0	1 Unit Failed
* 700 of the 1700 Spikes were with an applied voltage of 208 VAC.					

On 28 June 1996, spike testing of several different hybrid network models was completed. The 120-VAC model was tested for the 115-VAC configuration, and the 440-VAC and 480-VAC models were tested for the 440-VAC configuration. The energy rating for the 120-VAC model is 846 joules, which is considerably higher than the expected transient level of 60 joules. The energy ratings for the 440-VAC and 480-VAC models ranged from 1040 joules to 3840 joules, which is also considerably higher than the expected transient level of 375 joules.

The 120-VAC model was subjected to approximately 5000 line-to-ground and 5000 line-to-line voltage spikes of amplitude 1000 VDC (60 joules, 2-/50-µsec waveform), with no degradation in performance. The test setup was then changed and the 120-VAC model was subjected to 1000 line-to-ground and 200 line-to-line voltage spikes of amplitude 2500 VDC (375 joules, 2-/50-µsec waveform), before a failure occurred.

The 440-VAC and two of the 480-VAC models were subjected to approximately 5000 line-to-ground and 5000 line-to-line voltage spikes of amplitude 2500 VDC (375 joules, 2-/50-µsec waveform), with no degradation in performance. Unfortunately, two of the 480-VAC models with slightly lower energy ratings failed catastrophically. One of the 480-VAC models that failed experienced a degradation in performance after being subjected to approximately 2500 line-to-ground voltage spikes of amplitude 2500 VDC. The clamping voltage shifted from approximately 1800 VDC to 1100 VDC. Although the 480-VAC model was degraded, it continued to clamp the voltage spikes. The 480-VAC model was subjected to an additional 2500 line-to-ground voltage spikes for a total of 5000 spikes, with no further degradation. The test setup was then changed and the 480-VAC model was subjected to line-to-line voltage spikes. After applying 2650 line-to-line voltage spikes of amplitude 2500 VDC, the 480-VAC model failed catastrophically, emitting a black powder (where the cables exit the device) and tripping a 100 A circuit breaker (AQB-A101). The failure mode was a short-circuit. It should be noted that the 480-VAC model enclosure remained cool to the touch, up until the point when it failed. A summary of the hybrid network test results can be found in Table 3.

TABLE 3. HYBRID NETWORK SPIKE VOLTAGE TEST RESULTS

Model	Spike Voltage	Energy Rating (per phase)	Number of Line-to-Ground Spikes Applied	Number of Line-to-Line Spikes Applied	Result
120-VAC, 3-Phase	1000 VDC	846 joules	5000	5000	Passed
440-VAC, 3-Phase	2500 VDC	1040 joules (L-G) 2080 joules (L-L)	5125	5025	Passed
440-VAC, 3-Phase	2500 VDC	2080 joules	5000	5000	Passed
480-VAC, 3-Phase	2500 VDC	1500 joules	2880	1102	Failed
480-VAC, 3-Phase	2500 VDC	1920 joules	* 5000	2650	Failed
480-VAC, 3-Phase	2500 VDC	3840 joules	5000	5000	Passed
480-VAC, 3-Phase	2500 VDC	3840 joules	5000	5000	Passed
* The clamping voltage dropped from 1800 VDC to 1100 VDC after 2500 spikes.					

The technology of the hybrid network models appears to be promising. The 120-VAC, 440-VAC, and two of the 480-VAC models were able to clamp over 10000 voltage spikes each and withstand the 35 percent over-voltage condition with no degradation in performance. The two 480-VAC models with slightly lower energy ratings were still able to clamp a large number of voltage spikes before they failed. Since these devices can fail in a short-circuit mode, considerations should be given to alleviate the effects of this failure mode by using only the fused models and by containing the products of combustion that result from the short-circuit.

TVSSs may be implemented as shown in Figure 1 above, or they may be incorporated into the design of the equipment. This will have to be decided by the acquisition managers, engineers, and program managers. Not only is it important that any candidate TVSSs be tested to verify their durability and effectiveness at clamping voltage spikes, but the clamping voltage must be carefully selected as well. Consideration should also be given to the coordination of these devices (similar to circuit breaker coordination).

CONCLUSIONS

A number of approaches for meeting the stringent electrical interface requirements for U.S. Navy shipboard equipment have been identified. For mission-critical military equipment that is normally powered from the 440-VAC, 60-Hz bus, the NSEPS is an effective approach to meeting the electrical interface requirements of MIL-STD-1399, Section 300 and MIL-STD-2036. COTS equipment, UPSs, and power conditioners are also options, but are not as readily available with 440-VAC ratings.

For non-mission critical and COTS equipment that is normally powered from the 115-VAC, 60-Hz bus, UPSs and power conditioners can be effectively employed to meet the electrical interface requirements of MIL-STD-1399, Section 300 and MIL-STD-2036.

For electronic equipment that is susceptible to spikes, TVSSs rated considerably higher than 60 Joules for 115-VAC systems and considerably higher than 375 joules for 440-VAC systems can be used to clamp the voltage within the acceptable limits of the equipment.

COTS equipment can be used in a shipboard environment, provided the electrical interface requirements of MIL-STD-1399, Section 300 and MIL-STD-2036 are met, or suitable measures are taken to buffer the COTS equipment. When ride-through of long duration power interruptions is required, UPSs can be used to buffer the COTS equipment. When ride-through of momentary power interruptions is required, power conditioners with 150-msec hold-up can be used to buffer the COTS equipment. Another option is to ruggedize the COTS equipment. For mission-critical applications, the COTS equipment may also need to be ruggedized to meet the additional environmental requirements. In this case, the UPSs and power conditioners may need to be ruggedized as well, or the NSEPS can be used. As noted earlier, it is important that any candidate COTS equipment be tested to verify conformance with the electrical interface requirements noted above.

APPENDIX A

DRAFT COMMERCIAL ITEM DESCRIPTION UNINTERRUPTIBLE POWER SUPPLY FOR SHIPBOARD APPLICATIONS

1. SCOPE

1.1 Scope. This draft commercial item description (CID) covers rack-mounted, cord connected uninterruptible power supplies (UPS) suitable for shipboard installations.

2. DETAILED REQUIREMENTS

2.1 Input power. Units shall be suitable for operation from ungrounded 115 VAC, +10 percent, -15 percent, single phase power. Units shall withstand voltage transients of +35 percent, -20 percent for a period of 2-min. Units shall be suitable for operation from 50 Hz ±5 percent and 60 Hz ±5 percent power.

2.2 Surge suppressors. When supplied with surge suppressors, units shall withstand multiple 1000-VDC, 60-joule voltage spikes with a 2-µsec rise time and 50-µsec duration. Units shall withstand 5000 voltage spikes applied line-to-line, and 5000 voltage spikes applied line-to-ground.

2.3 Harmonics. Unit input current harmonics with a nonlinear load shall not exceed 3 percent of the fundamental for any single harmonic, and 5 percent total harmonic distortion (THD). Unit output voltage harmonics with a nonlinear load shall not exceed 3 percent of the fundamental for any single harmonic, and 5 percent THD. A nonlinear load shall be considered a full-wave bridge rectifier feeding a constant-power load. Unit power factor with a resistive load shall be greater than 0.95.

2.4 Leakage current. Unit leakage current shall not exceed 5 mA.

2.5 Output power. Unit output voltage shall be 115 VAC ±10 percent under any condition specified herein. Loss of output voltage shall not exceed 50-µsec under any operating condition, including voltage detection and transfer delays. Unit output frequency shall be 50 Hz ±0.5 percent or 60 Hz ±0.5 percent under any condition specified herein, including input frequency transients of 50 Hz ±5 percent and 60 Hz ±5 percent. Unit output voltage harmonics shall be as specified in requirement 2.3 above.

2.6 Overload. Units shall withstand an overload of 150 percent of nominal rating for a period of 30-sec with no degradation in output power.

2.7 Short circuit. Units shall withstand, without damage, a short circuit on the unit output.

2.8 Efficiency. Under full load nominal conditions, unit efficiency shall be greater than 95 percent.

2.9 Battery re-charge. Unit batteries shall be recharged to greater than 90 percent of full capacity in less than 4-hrs following full discharge.

2.10 Environmental conditions. Units shall be suitable for operation in a temperature range of 0 deg C to 40 deg C, with 5 percent to 95 percent relative humidity. The unit shall be suitable for storage in a temperature range of -30 deg C to 70 deg C.

2.11 Visual indicators. Units shall provide indication of when the unit is energized; indication of when unit output is being powered from unit batteries; and indication of low battery voltage conditions.

2.12 Batteries. Batteries shall be of the maintenance free, starved electrolyte type.

2.13 Switches. Units shall be provided with an on/off switch. For safety considerations when performing maintenance, switches shall remove all input power to the unit including line and return conductors. Switches shall not disconnect safety ground conductors. It should be noted that units will be powered from ungrounded power sources as specified in requirement 2.1 above (i.e., the voltage of unit line and return connections will be floating with regard to safety ground).

2.14 Receptacles. Units shall be provided with a minimum of two general purpose, 2-pole, 3-wire, 15-A, 115-VAC convenience outlets.

2.15 Cord. Unit power supply cord shall be of the hard service cord type S or SO, or of the junior hard service cord type SJ or SJO in accordance with the requirements for flexible cords and cables.[A-1] Unit power supply cord shall include a safety ground conductor.

2.16 Mounting. Units shall be suitable for mounting in a standard rack in accordance with the standard for racks, panels, and associated equipment.[A-2]

2.17 Safety. Units shall be in accordance with the UPS standard of safety[A-3] and the requirements specified herein. Units shall not expose personnel to safety hazards when performing installation, operation, maintenance, testing or repair of units. Units shall not expose personnel to voltages in excess of 30 VAC root-mean-square (RMS) or 60 VDC when performing installation, operation, maintenance, testing or repair of the units. All exposed surfaces of the unit shall be at ground potential. Units shall be certified by a nationally recognized testing laboratory (NTRL) accredited for UPS certification by the Occupational Safety and Health Administration (OSHA), U.S. Department of Labor.

[A-1] National Electrical Code, ANSI/NFPA 70, 1990.

[A-2] Electronic Industries Association, Engineering Department, Racks, Panels, and Associated Equipment, ANSI/EIA-310, 1977.

[A-3] Underwriters Laboratory, Standard of Safety, Uninterruptible Power Supply, UL 1778.

APPENDIX B

NAVSEA LETTER OF ENDORSEMENT
DATED 25 APR 93

DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
2531 JEFFERSON DAVIS HWY
ARLINGTON VA 22242-5160

IN REPLY REFER TO
3900
OPR: 06K2B
Ser 05E/05E1-033
25 APR 93

From: Commander, Naval Sea Systems Command

Subj: COMBAT SYSTEMS ELECTRICAL POWER MOBILE TEST FACILITY

1. Degradations and failures of shipboard combat system equipment due to variations of shipboard electric power can result in costly investigations and corrections.

2. Naval Sea Systems Command has been developing a means to identify potential electrical interface problems so that corrections to equipment can be implemented prior to shipboard installation. The recently completed Combat Systems Electrical Power Mobile Test Facility represents a significant new capability for ensuring compatibility between combat system equipment and shipboard electrical power systems.

3. The Mobile Test Facility, designed and operated by engineers at the White Oak Detachment of the Naval Surface Warfare Center's Dahlgren Division, represents a unique capability. It consists of computer controlled electric power generation and measurement equipment which can simulate electric power characteristics and enable analysis of their effects on equipment performance. It provides the capability to test equipment compliance with electric power requirements prior to shipboard installation. This facility can also serve as a research laboratory to support any development of future equipment and can be transported across country to remote locations.

4. The Mobile Test Facility now provides equipment developers a means to fully test shipboard electrical power interface requirements. Program managers and contractors should find the Mobile Test Facility a useful asset for enhancing shipboard combat system readiness.

A. E. CROUT
Director,
Electrical Engineering Group
Ship Design and Engineering Directorate
By direction of the Commander,
Naval Sea Systems Command

P. PRIKALS
Assistant Deputy Commander for Combat Systems Engineering
Ship Design and Engineering Directorate
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